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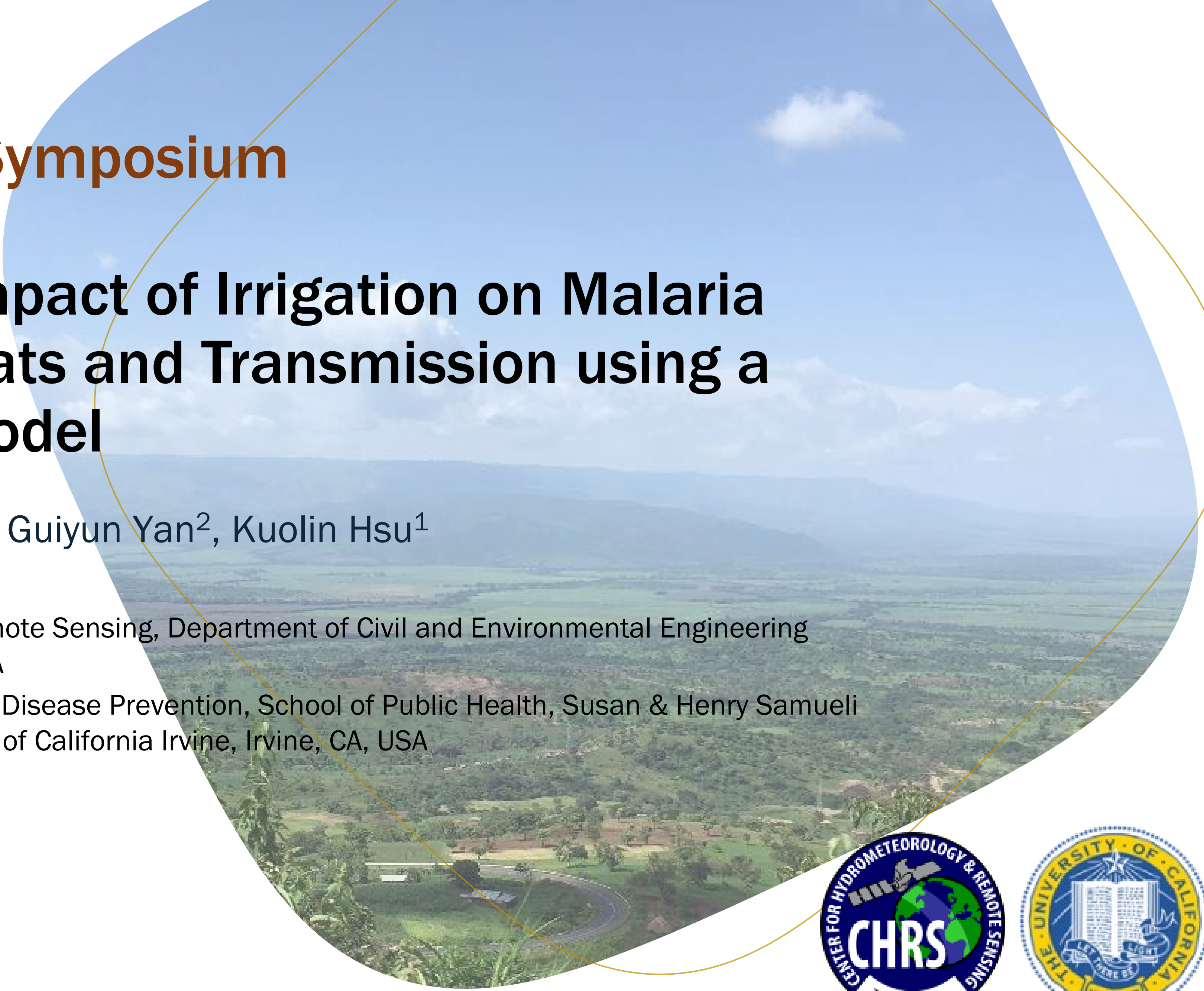
Investigating the Impact of Irrigation on Malaria Vector Larval Habitats and Transmission using a Hydrology-based Model

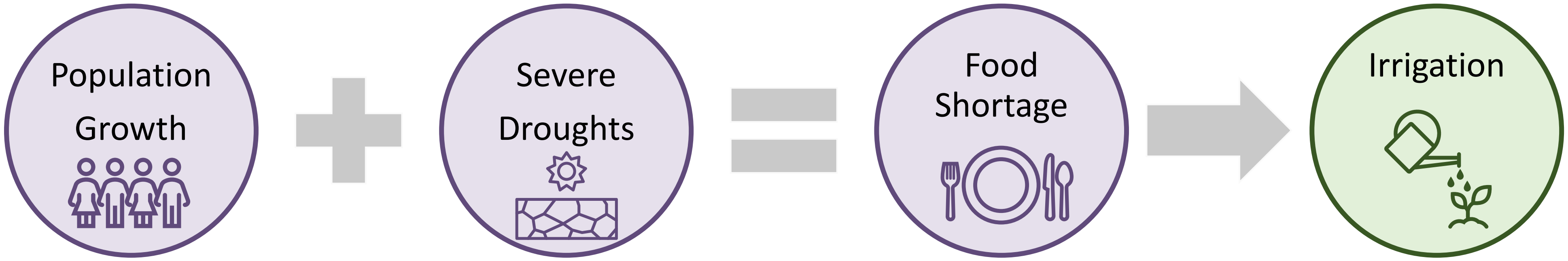
Ai-Ling Jiang[1], Ming-Chieh Lee[2], Guiyun Yan[2], Kuolin Hsu[1]

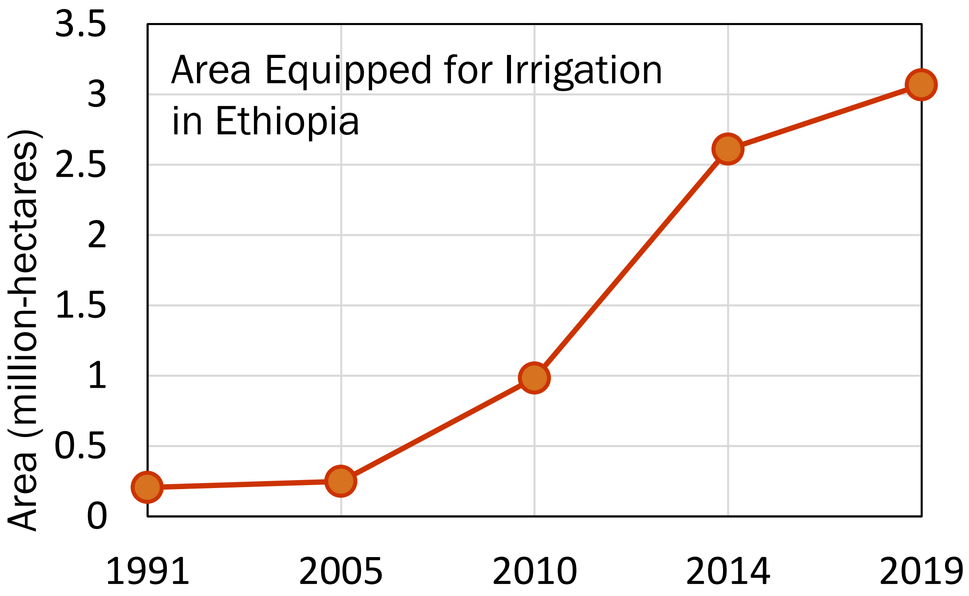
1. Center for Hydrometeorology and Remote Sensing, Department of Civil and Environmental Engineering University of California, Irvine, CA, USA
2. Department of Population Health and Disease Prevention, School of Public Health, Susan & Henry Samueli College of Health Sciences, University of California Irvine, Irvine, CA, USA



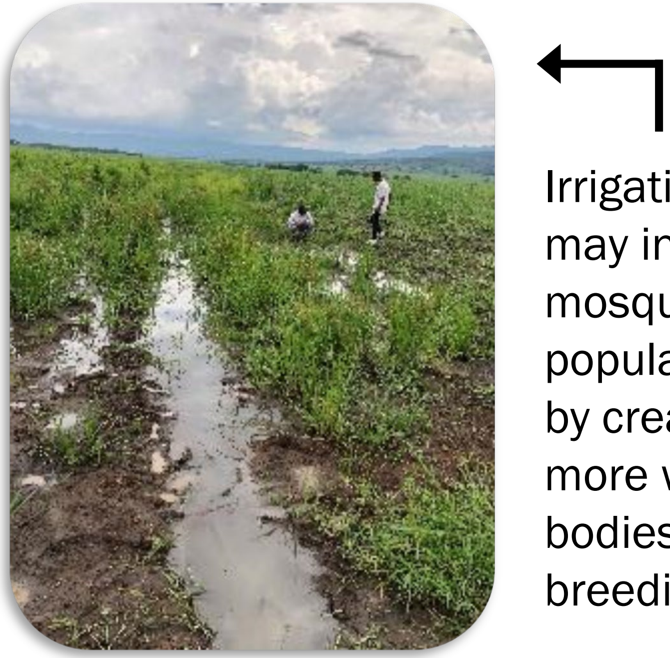
May 24th, 2023

Expanding irrigation could exacerbate malaria transmission in Africa





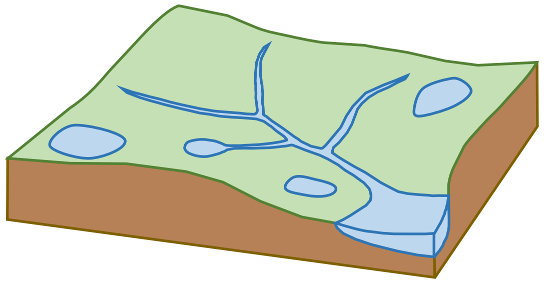
Gebul et al., 2021



Irrigation may increase mosquito population by creating more water bodies for breeding

Malaria models typically oversimplify hydrology when simulating larval habitat dynamics

Habitats in the Field

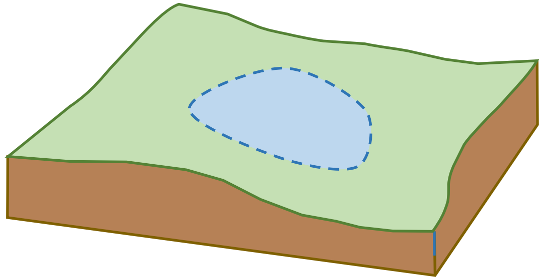


Default EMOD

Rainfall
Temperature
Humidity

→ Simplified Equations (EMOD) →

Conceptually Lumped Habitat



- Habitat area simulated conceptually and highly dependent on parameter calibration

$$H^t = H^{t-1} + P_{rain}{}^t \lambda D_{cell}^2 - H_{t-1}\tau\Delta t \quad (1)$$

$$H^t = \lambda D_{cell}^2 = constant \quad (2)$$

$P_{rain}{}^t$: Rainfall ;
λ: **Scale factor for habitat area**;
D_{cell}^2: Node Area;
τ: **Decay Rate**

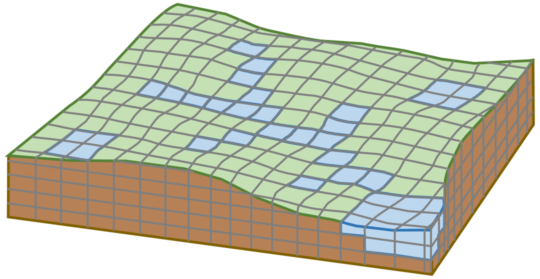
Eckhoff, 2011

Integrated EMOD

Rainfall
Temperature
Humidity
Irrigation
Energy Radiation
Topography
Land Cover
Soil Type
… etc.

→ Hydrologic Model (ParFlow-CLM) →

Spatially Distributed Habitats



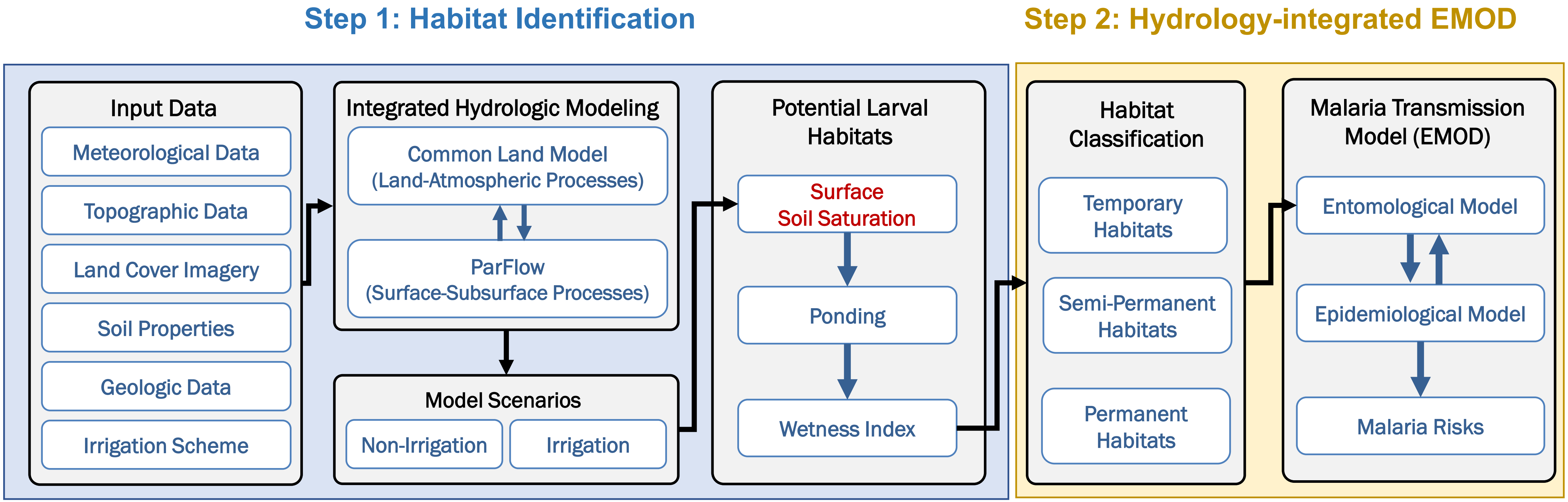
- Habitat area simulated explicitly based on physics

$$H_t = F_t D_{cell}^2$$

F_t: Fractional area of habitat simulated by ParFlow – CLM within node ;
D_{cell}^2: Node area;

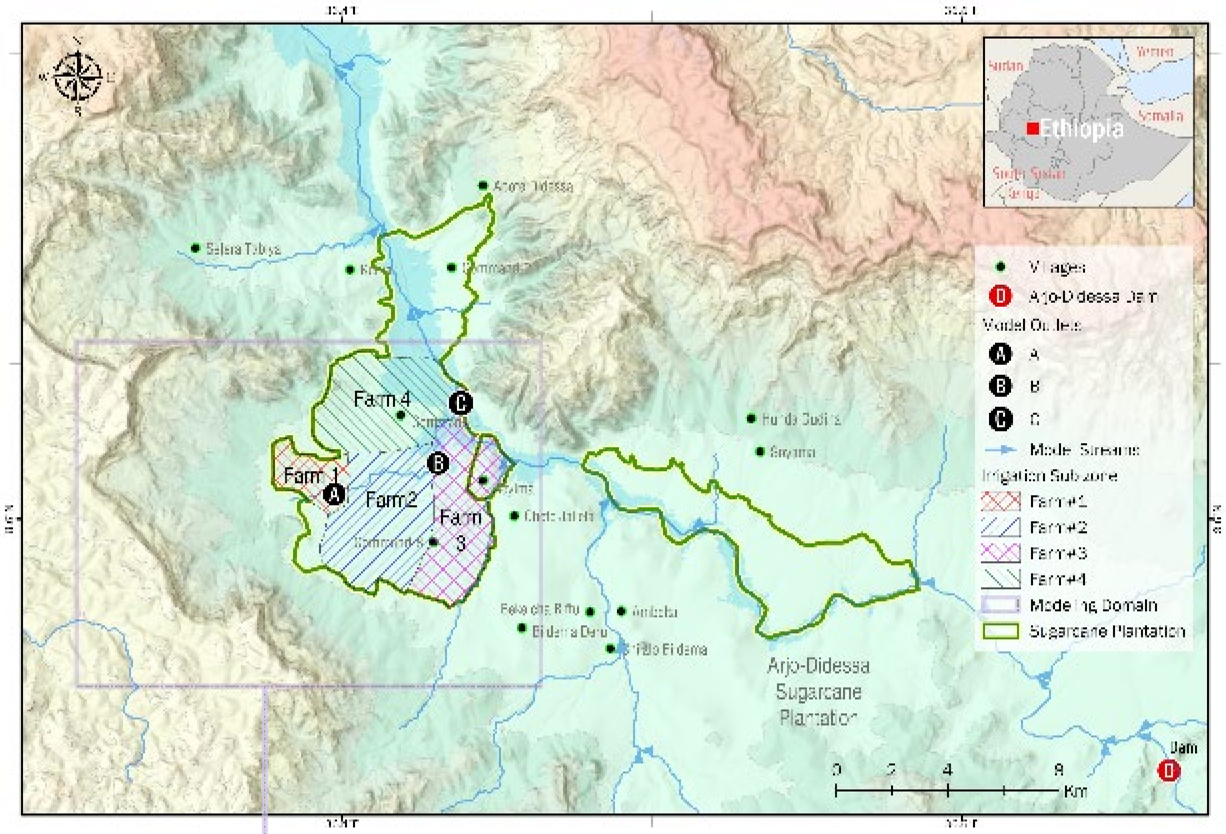
(1): Equation of temporary or semi-permanent habitat in Default EMOD
(2): Equation of permanent habitat in Default EMOD

ParFlow-CLM was integrated with EMOD to improve habitat representation



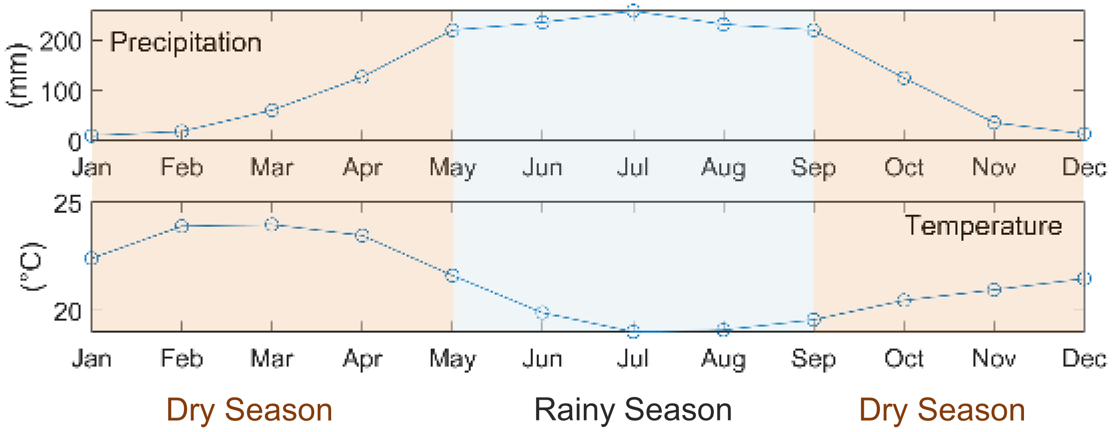
Jiang et al., 2021

Study area: sugarcane plantation in Arjo-Didessa, Ethiopia



- Domain: 208 km^2; Depth:100 m
- Resolution: dx = dy = 50 m; varying dz
- 10 Subsurface layers

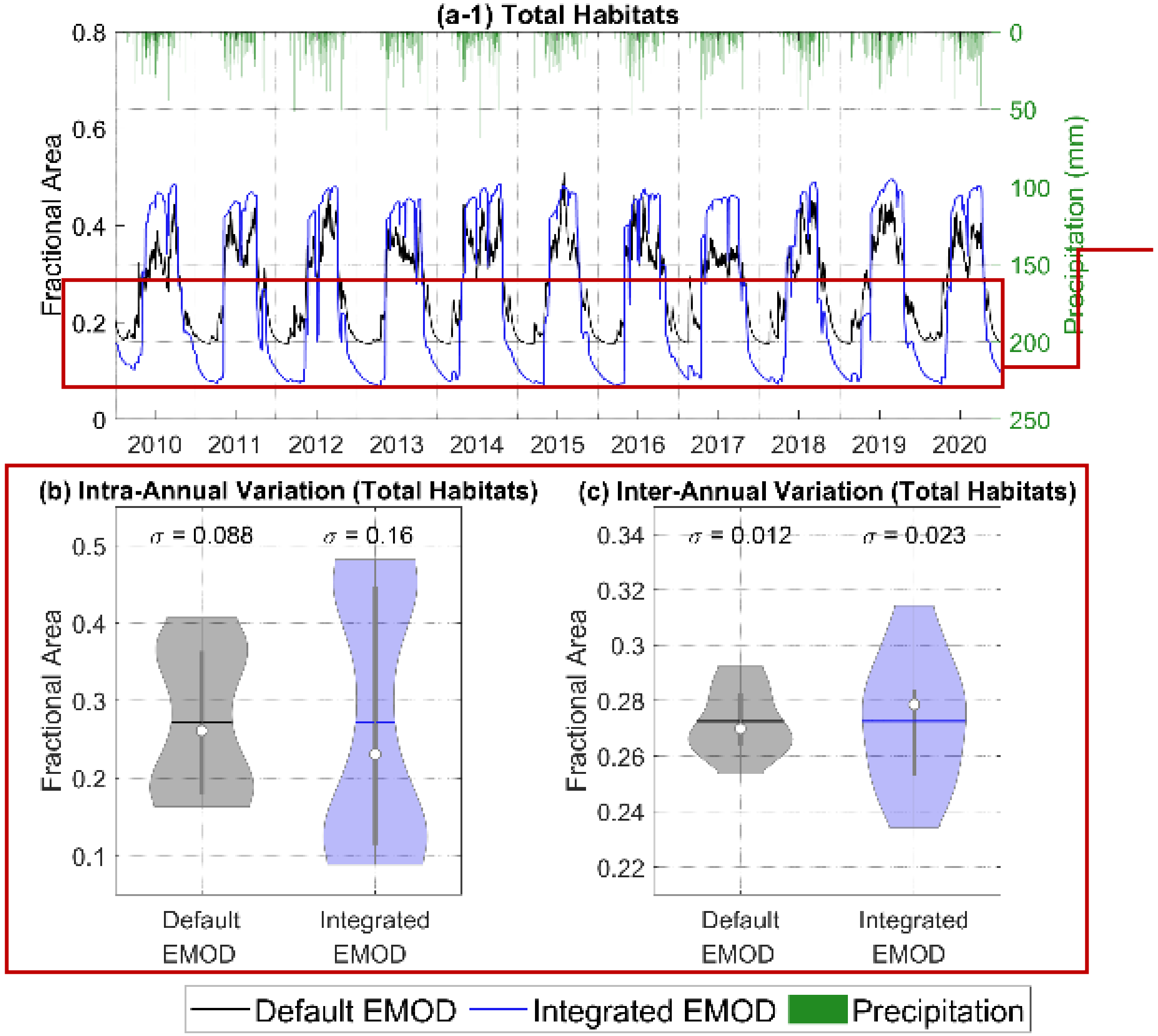
Climatology in Arjo, Ethiopia



- Simulation period: 2000-2020
- Scenarios modeled:
  - Non-Irrigation
    - Default EMOD
    - Integrated EMOD
  - Irrigation (starting from 2012)
- Rotating irrigation applied during dry months

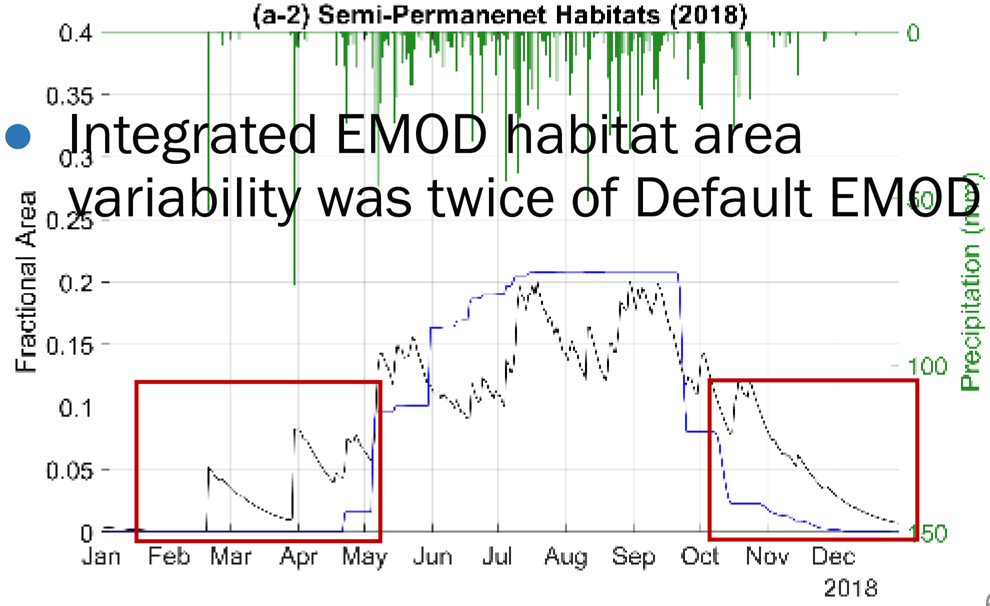
Default EMOD unable to fully represent habitat area variability

Assumption: Mean habitat area of Default EMOD and Integrated EMOD were adjusted to be same

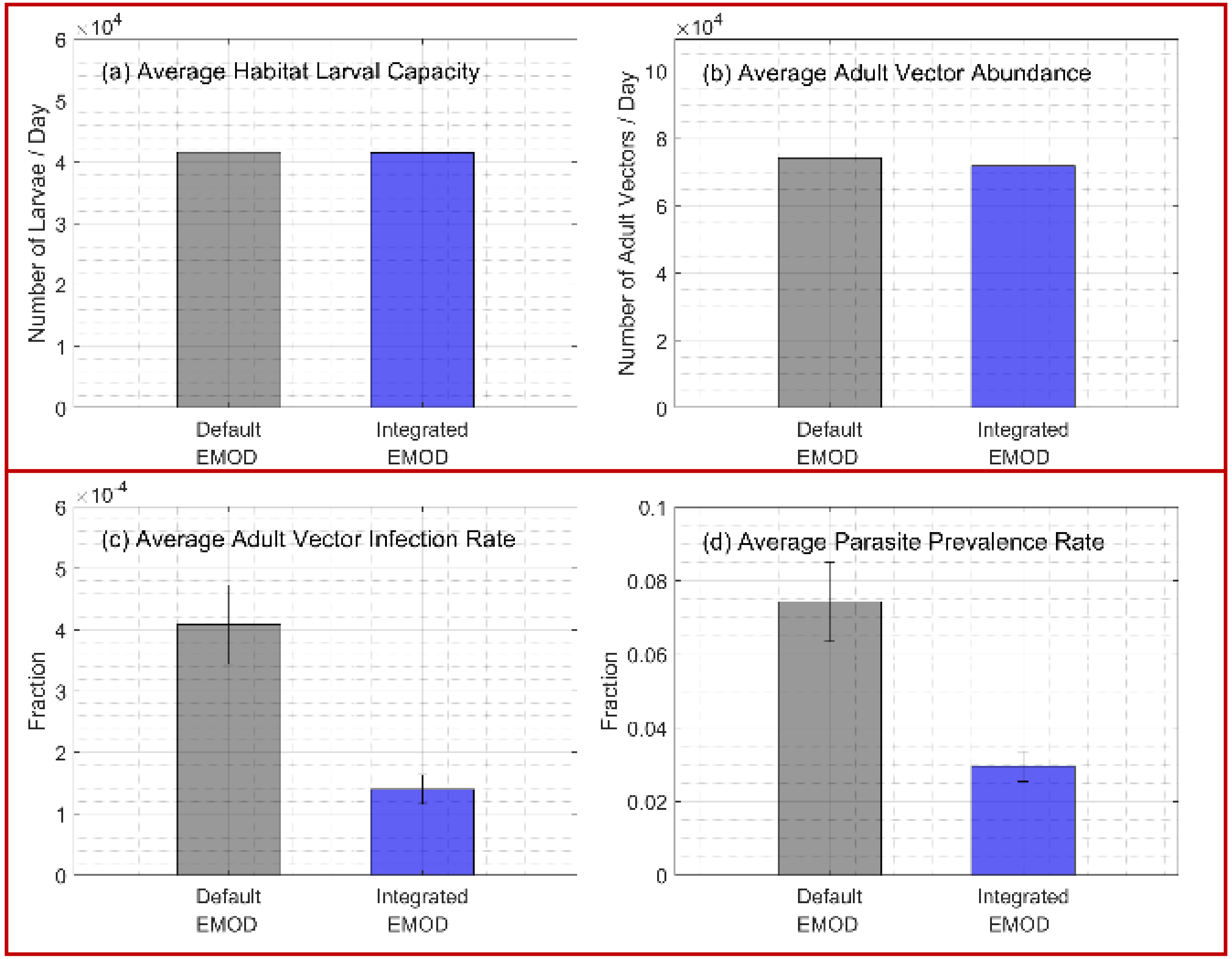


- Default EMOD had higher lows
  - Constant permanent habitat area
  - Infiltration mechanism missing for temporary and semi-permanent habitats

- Integrated EMOD habitat area variability was twice of Default EMOD

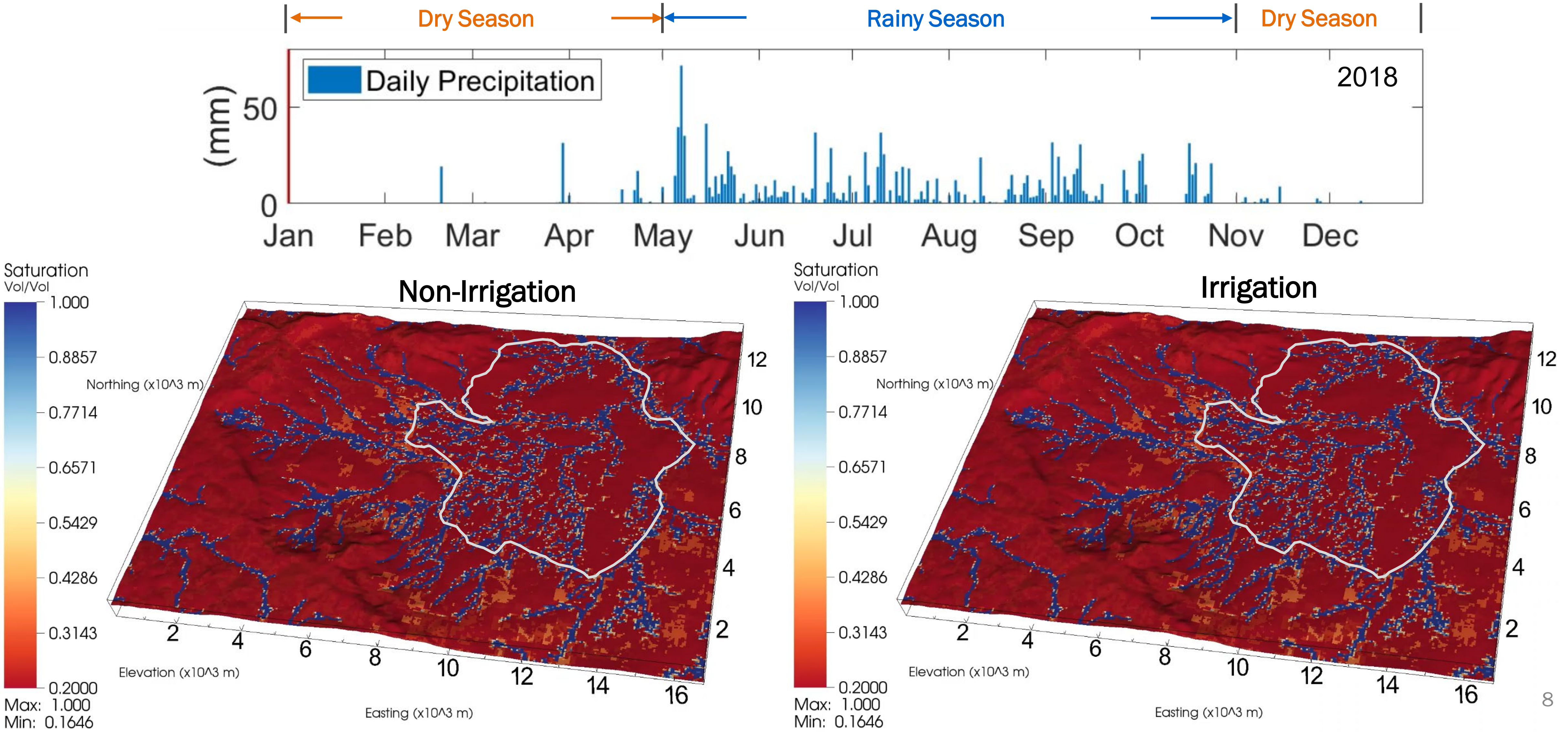


Higher variability of habitat area results in lower transmission

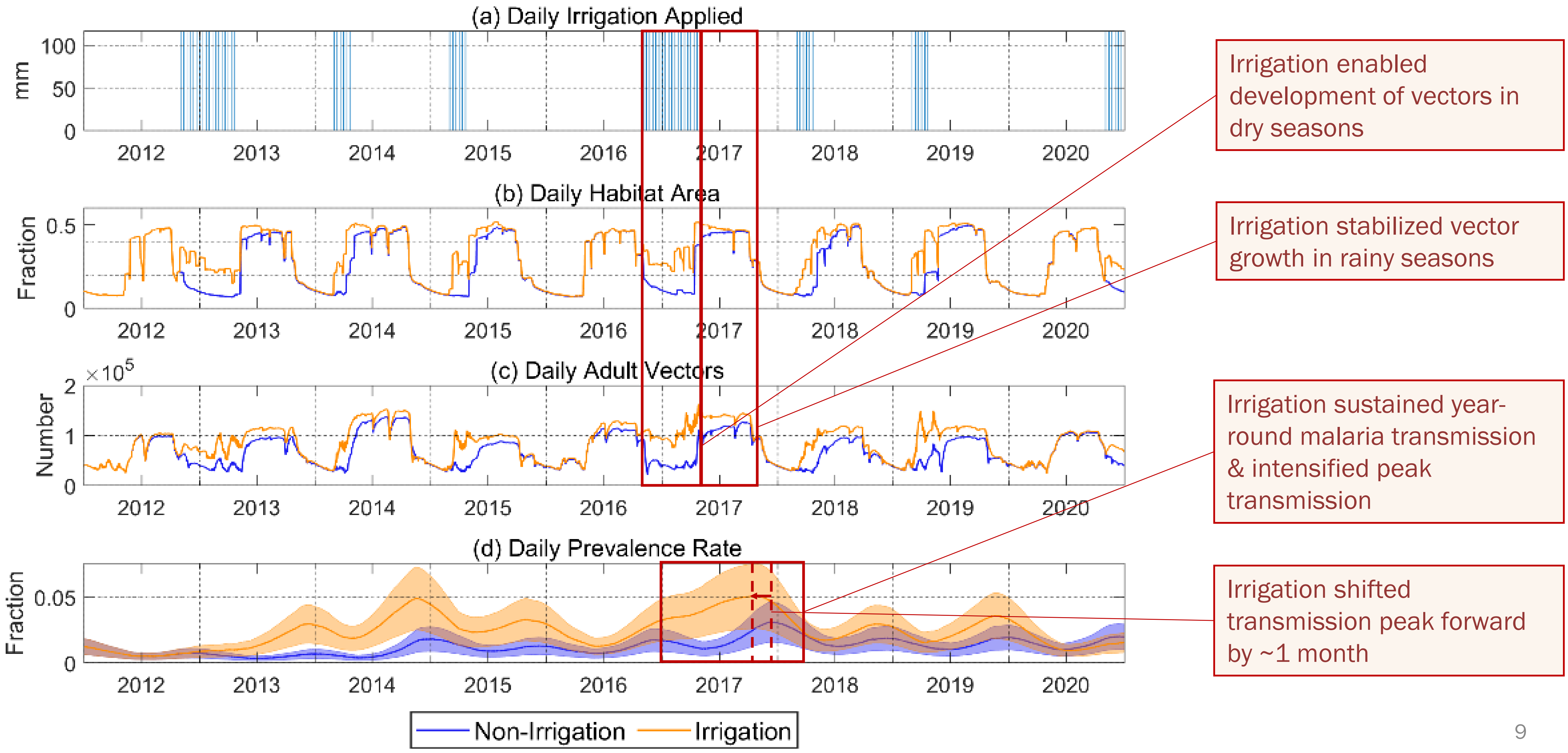


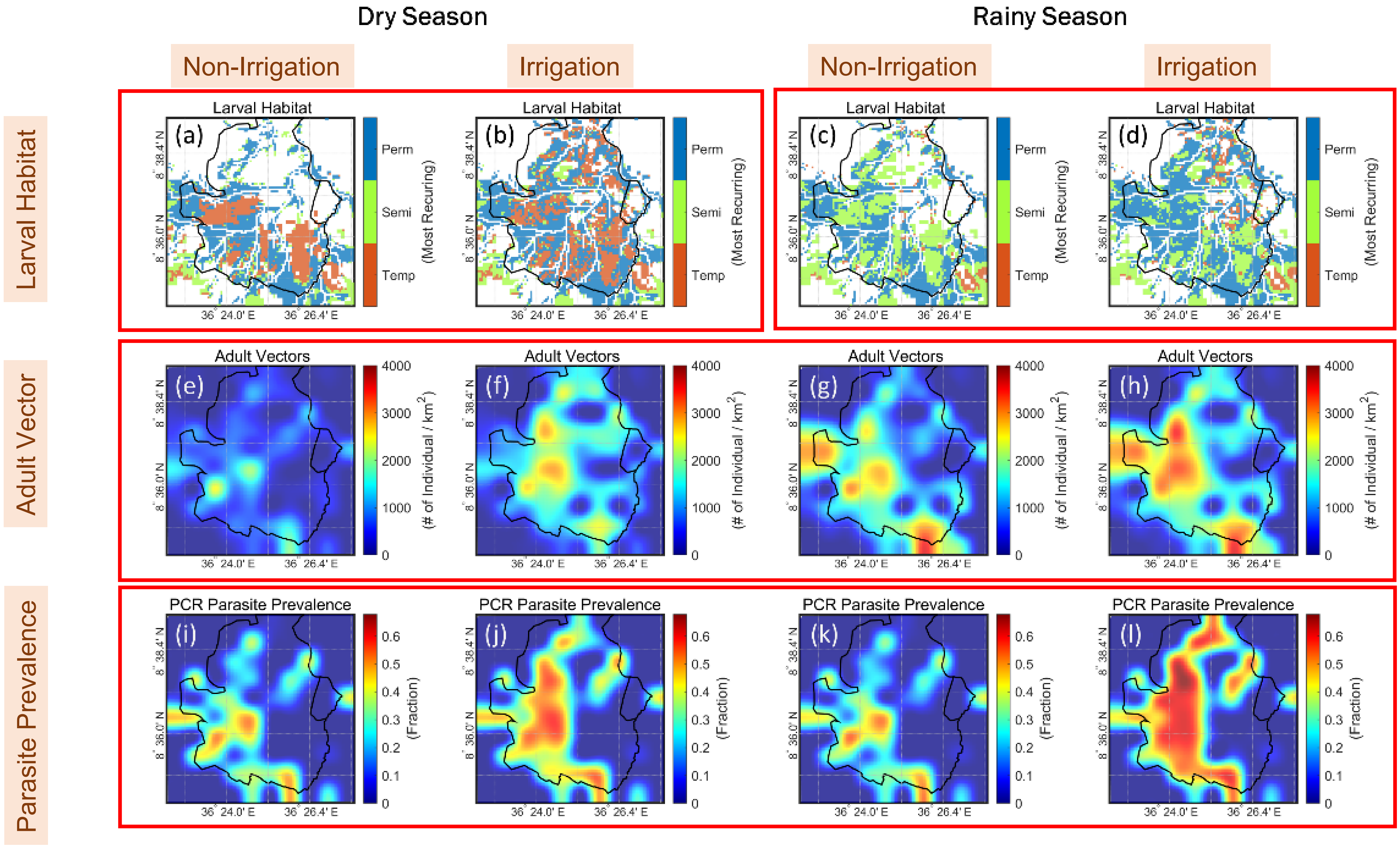
- Annual average habitat capacity and vector abundance were nearly identical
- But average vector infection rate was 2.9 times higher and average prevalence rate was 2.5 time higher in Default EMOD due to lower habitat area variability

Model captures response of surface soil saturation to rainfall and irrigation



Irrigation sustained transmission all year round and shifted peak forward by one month




Dry Season
Rainy Season
Non-Irrigation
Irrigation
Non-Irrigation
Irrigation
Larval Habitat
Adult Vector
Parasite Prevalence
Larval Habitat
(a)
(b)
(c)
(d)
Perm
Semi
Temp
(Most Recuring)
(Most Recurring)
Adult Vectors
(e)
(f)
(g)
(h)
4000
3000
2000
1000
0
(# of Individual / km²)
PCR Parasite Prevalence
(i)
(j)
(k)
(l)
0.6
0.5
0.4
0.3
0.2
0.1
0
(Fraction)
8° 38.4' N
8° 36.0' N
36° 24.0' E
36° 26.4' E

Conclusion

- We integrated hydrologic modeling to EMOD to spatially simulate malaria transmission by resolving habitat heterogeneity
- The coupling framework enhanced larval habitat area variability which resulted in a lower malaria transmission prediction
- Irrigation sustained malaria transmission year-round, intensifying and shifting the transmission peak forward by one month from the original period

References

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Stay tuned and thank you for your attention!

Contact: jiangal@uci.edu